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Asset liability management for pension funds using multistage mixed-integer stochastic programming

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Chapter 1

Introduction and Summary

Recently, my parents received a letter from the pension fund from which they get their pension payments every month. Good news. The benefit rights of this fund are fully indexed with respect to increases in the general wage level. My parents belong to the lucky ones that received a letter with good news: not every pension fund compensates the rights of retired people for increases in prices or wages over the previous year. Not only retired people may suffer from weak financial positions of pension funds, also some active participants are far from happy. They have to pay a larger fraction of their pensionable salary to the fund. This means less purchasing power for them. Moreover, also the supervisor shows his teeth: pension funds with very low funding ratios (ratios of the values of the assets and the liabilities) have to take corrective actions, such as an increase of the contribution rate, to strengthen the financial position of the fund. Moreover, funds that invest a lot in stocks, need additional buffers in order to make the pension fund less vulnerable to unfavorable financial developments.

What is the reason of the recent low funding ratios of many funds? Bad management? Too high restitutions a few years ago? Too low contribution rates? Too optimistic future expectations?

At least one thing is certainly true: the financial positions of almost all funds weakened, because of decreasing stock prices in the last years. From 1995 to September 2000, stock returns were exceptionally high, see for example Figure 1.1, where the development of the broadly diversified MSCI World-index is presented. These data are derived from Datastream [20]. Because daily data were only available from July 1998, the first part of the figure looks less smooth than the latter part. Before July 1998, monthly data were used.

The value of this index increased from 458 (on January 1, 1995) to 1160 (in March 2000). This means a return (even without dividends) of more than 150 percent in 5 years and 3 months. Encouraged by such very high returns, many pension funds invested an increasing fraction of their assets in stocks, see for example the website of the Dutch central bureau of statistics, CBS [16].

It is not surprising that funding ratios of pension funds increased in those years. Some funds had generated such high reserves, that participants and sponsors had premium holidays. This means that active participants did not pay regular contri-

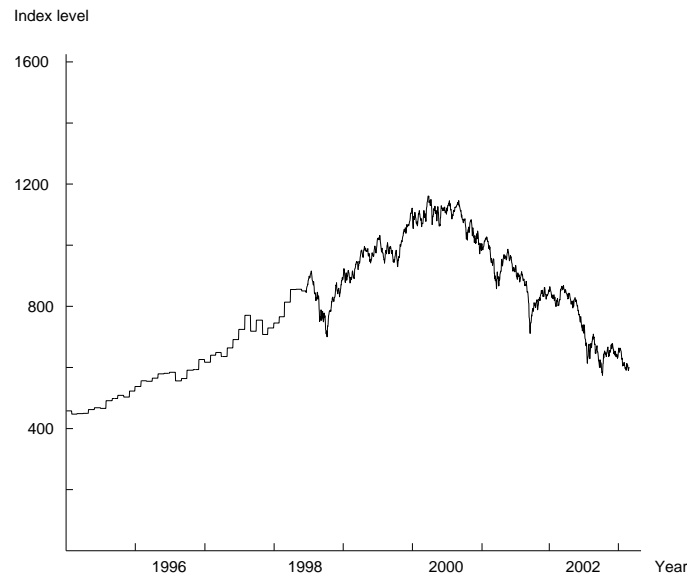


Figure 1.1: MSCI World-index from January 1, 1995 to March 1, 2003.

butions to the funds, whereas pension rights were still built-up. Moreover, some funds even made restitutions to their sponsor.

As we can also see in Figure 1.1, the MSCI World-index decreased gradually from March 2000 on. On March 1, 2003, its value was 598. This means that the index lost approximately 50 percent of its value in 3 years. Other stock indices showed similar performances, see Table 1.1. These data are also derived from Datastream [20]. From this table, it is clear that in all parts of the world stock prices declined.

Country	Index	Value on Jan. 1, 1995	Value on Sept. 1, 2000	Value on March 1, 2003	% change from 1995 to 2000	% change from 2000 to 2003
Great Britain	FTSE 100	3,062	6,672	3,553	+118	-47
The Netherlands	AEX	187	692	257	+270	-63
Switzerland	SMI	2,628	8,234	4,148	+213	-50
United States	Dow Jones	3,834	11,215	7,837	+193	-30
United States	Nasdaq	751	4,234	1,320	+464	-69
Japan	Nikkei	19,723	16,861	8,363	-15	-50
Hong Kong	Hang Seng	8,188	17,210	9,111	+110	-47

Table 1.1: Developments in stock indices in different parts of the world.

The combination of high fractions of assets invested in stocks and very low returns on them, eroded the financial position of many funds. The pension funds in The Netherlands lost approximately €20 billion in 2002, see the website of CBS [16]. The financial position of Dutch pension funds deteriorated so fast, that it attracted a lot of attention in the press.

To get an indication of recent development of the financial position of pension funds in The Netherlands, Figure 1.2 is added. This figure is based on a similar figure, which appeared in NRC Handelsblad [95]. The numbers in this figure are based on those of the supervisor of Dutch pension funds, PVK.

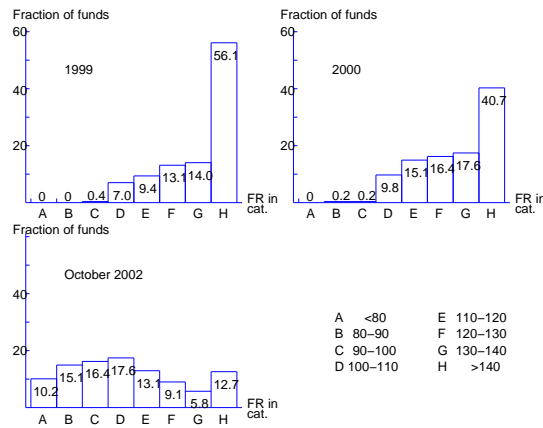


Figure 1.2: The development of the funding ratio (FR) of the Dutch pension funds in recent years.

Also according to NRC Handelsblad [96], in October 2002, 300 pension funds were underfunded. Together, these 300 funds had a shortage of €23 billion. In 2003 these problems were not solved. De Volkskrant [98] wrote that the funding ratio of a quarter of the ‘bedrijfstakpensioenfondsen’ (pension funds related to companies in the same branch of industry) was too low.

From this brief financial history it is clear that pension funds face one major source of risk: uncertainties with respect to future developments of financial markets. One can imagine that there are many more uncertainties the board of pension funds have to deal with. Some of them are described in Section 1.2.4.

To manage risks (and to better understand them), pension funds and their advisors have developed financial models with which they compute the impact of future capital market developments on their financial position. These so-called ALM models focus on the decision making problem of pension funds. In this thesis, we present the ALM model we have developed. In this model detailed risk measures are incorporated. Many of such ingredients were not considered before in ALM models described in the literature. We consider not only short-run risks (by which we mean unfavorable developments which will be revealed within one year), also

risks associated with longer time periods are taken into account. Moreover, flexibility plays a key role: the board of the fund can periodically change its decisions with respect to investments, contributions, and indexation. In this way, they can react on observed developments of financial markets and on developments associated with the participants of the fund. In order to describe the uncertainties in the model (like future returns on assets), we have developed a *scenario generator* to find future developments of all uncertain parameters.

Our ALM model is an optimization model, so its aim is to specify the conditions that the decision variables have to satisfy, together with the consequences by which their numerical values are judged. That is, from a mathematical point of view, such a model specifies precisely the set of feasible solutions by means of constraints, and the subset of optimal solutions by means of the objective function. Of course, for practical applications, model building should be followed by numerical calculation of solutions. Indeed, there exist algorithms to find an optimal

solution of our ALM model. However, for realistic sized instances they need astronomically large solution times. One of the reasons is the complication due to the flexibilities. Therefore, in order to find good (but not necessarily optimal) solutions in reasonable time, we developed a heuristic approach.

Before we describe our ALM model, we first consider the Asset Liability Management (ALM) problem for pension funds. In Section 1.1 we describe what a pension is, which types of pensions exist, and the various ways in which pension rights are accumulated. Also historical developments are presented, not only in The Netherlands, but also in some large countries. At the end of the section, also expected future developments will be considered. In the second section the various aspects are discussed, which are directly related to ALM problems: interested parties, instruments which are at the disposal of the boards of pension funds, and the supervisor. Also several types of risk are discussed. In the last section of this chapter, we describe ALM models and solution techniques. Finally, we describe the key characteristics of our ALM model.

1.1 Pensions and pension funds

In this section, some fundamental concepts with respect to pensions are described. We also present figures to show how pensions are actually arranged, especially in The Netherlands, but also in some major countries. Moreover, we present some general information on pension funds and the relevant legislation in The Netherlands. The legislation used in this thesis was found on the website of the PVK [75] in April 2003. At the end of this section, we pay attention to future challenges.

1.1.1 Pensions as second pillar facility

Pension is a generic term for periodic payments which replace the former salary in case of reaching a certain age, disability or death of the employee. Many types of pension exist. Moreover, several ways to build up pension rights exist. There are also many types of pension funds. We will describe these types of pension funds in the next subsection.

The basis of the existence of pension funds is solidarity between generations and between participants of a pension fund. After all, some participants will never profit from the contributions they made, because they die early. On the other hand, other participants live longer than average. As a result, they will receive more money from the fund than they have actually saved by themselves. Because many funds have a large number of participants, risks can be reduced.

One can distinguish three pillars concerning old age, disability, and surviving relatives provisions. The first pillar involves the provisions by the government. In The Netherlands, these are the Algemene Ouderdomswet (AOW, an old age provision), the Algemene Nabestaandenwet (ANW, a surviving relatives provision), both social insurances, and the Wet op de Arbeidsongeschiktheidsverzekering (WAO, a disability provision), an insurance by employees.

The second pillar covers the pension scheme in the relationship between the employer and the employee. The third pillar consists of individual life insurances, which each individual can take out by a life insurance company. They are independent from labor relations.

1.1.2 Types of pension funds

On January 1, 2002, there were 889 pension funds in The Netherlands. These funds can be categorized in funds related to a single company, funds related to companies in the same branch of industry, and funds for individuals who have the same occupation. We describe these three types of funds briefly below.

- **Pension funds related to a single company**

In this type of fund, participating employees are all employed in the same company. Participation for all employees is mandatory. Examples of pension funds in The Netherlands that belong to this category are the funds of Akzo Nobel, Philips, Shell, and Unilever.

- **Pension funds related to companies in the same branch of industry**

Participating employees are all employed in companies in the same branch of industry. Also in this type of fund, participation is mandatory. Examples in The Netherlands are Algemeen Burgerlijk Pensioenfonds (ABP), and Pensioenfonds voor de Gezondheidszorg, Geestelijke en Maatschappelijke Belangen (PGGM).

- **Pension funds for individuals who have the same occupation**

Participants in these funds are all professionals who have their own practice, and all work in the same discipline. In this case, no relationship employee-employer exists. Participation can be mandatory. Examples of professions which fall into this category are medical specialists, dentists, and physiotherapists.

- **Other types of funds**

Most pension funds fall in one of the first three classes mentioned above. In addition, there are some saving funds for companies and one pension fund that is provided by law (the notarial pension fund).

Type of fund	2002		1998	
	Number	Percentage	Number	Percentage
Related to a single company	779	87.6	870	90.0
The same branch of industry	92	10.3	79	8.2
Individuals	11	1.2	11	1.1
Other	7	0.8	7	0.7
Total	889	100	967	100

Table 1.2: Numbers of pension funds in The Netherlands in 2002 and 1998, split-up according to the type of fund.

In Table 1.2 an overview is given of the numbers of pension funds in 2002 and 1998, for every type of pension fund described above. We see that most funds are related to a single company. Because of mergers, their total number decreased the last four years. At the same time, we see an increasing number of pension funds related to companies in the same branch of industry.

1.1.3 Types of pensions

Every type of pension provides the participant with an income after some event has happened. In this section, we discuss the most important types of pensions.

- **Retirement pension**

This is a pension for the financial care of a person, after the in the pension rules described pensionable age is reached. Generally, this payment is made lifelong.

- **Widow's pension**

This is a form of surviving relatives pension, that is paid to the widow(er) of a participant of the pension regulation. Generally, this payment is also made lifelong.

- **Partner pension**

This is the equivalent for the above described widow(er) pension. This pension applies for people who live together without being married, and satisfy a number of conditions.

- **Orphan pension**

This is a form of surviving relatives pension, that is paid to the child(ren) of a participant of the pension regulation. This type of payment is made, till the child(ren) has (have) reached a prespecified age.

- **Pension in case of disability**

This type of pension is made after the participant of the fund has become incapacitated for work.

Not all pension funds have all types of pension payments. In Table 1.3 we give an overview of both the absolute numbers and the percentages of the pension funds, which offered in 2002 and 1998 the above discussed types of pensions to their participants.

Type of pension	2002		1998	
	Number	Percentage	Number	Percentage
Retirement pension	835	93.9	932	96.4
Widow's pension	846	95.2	940	97.2
Partner pension	651	73.2	660	68.3
Orphan pension	832	93.6	919	95.0
Pension in case of disability	426	47.9	407	42.1
Number of funds	889		967	

Table 1.3: Numbers of the types of pensions offered by pension funds in The Netherlands in 2002 and 1998.

We conclude that almost all pension funds offer retirement, widow's, and orphan pensions. Roughly three quarters also have a partner pension and approximately half of the funds give a pension in case of disability.

Moreover, we see that the different types of pensions which are recorded in the pension regulation, are not much changed in the last five years.

1.1.4 Pension systems

In the Dutch law, three pension systems (i.e. systems to build up pension rights) are distinguished: a system based on the final salary, a system based on the average salary, and the so-called *defined contribution system*. The first two systems are also called *defined benefit systems*. In principle, the employer decides which of the systems is used. All these systems assume that pension rights will be built-up in 40 years. Now, we describe these three systems briefly, and also some variants of them.

Final pay systems

We distinguish two variants of the system based on final salaries.

- **Actual final pay system**

In this system, every wage increase not only affects the rights which will be built-up in the remaining years of service, but also in the previous built-up rights.

- **Moderate final pay system**

This system only differs from the system described above, in the sense that wage increases in the last years of service do not result in a higher pension.

This prevents that (extreme) wage increases in the last years of service result in a very high pension.

Systems based on the average earned salaries

Also for systems based on the average earned salaries, two variants are distinguished.

- **A system based on the actual average earned wage**
In this system, every wage increase influences the pension that will be built-up in the remaining years of service. The pension over previous years of service remains unaltered.
- **An indexed system based on the earned salaries**
This system is characterized by the fact that the pension based on past years of service are corrected for increases in prices or wages. Indexing is discussed in more detail in Section 1.2.3.

Defined contribution system

In a defined contribution system, the employer yearly transfers money (usually a percentage of the pensionable salary) to purchase a part of the employees' pension. The level of the pension depends on the number of years the pension contributions have been paid, the realized return in the years the pension has been built up, and the interest rate at the moment of retirement. This pension system generally also has fiscal consequences for the employee.

Systems to accumulate pension rights used in practice

In Table 1.4 we give an overview of the absolute and relative number of pension funds which use the different pension systems, both for 2002 and 1998.

System	2002		1998	
	Number	Percentage	Number	Percentage
Actual final pay	218	24.5	317	32.8
Moderate final pay	252	28.3	282	29.2
Average earned salaries	29	3.3	36	3.7
Indexed based salaries	126	14.2	90	9.3
Defined contribution	76	8.5	84	8.7
Other	188	21.1	158	16.3
Number of funds	889	100	967	100

Table 1.4: Numbers and percentages of the pension systems used by pension funds in The Netherlands in 2002 and 1998.

We see that the percentage of funds that uses the system based on the actual final salaries has decreased the last five years. Especially a shift towards indexed systems based on earned wages can be seen.

1.1.5 Indexation

When benefit payments are only expressed in nominal payments, and are not corrected for increases in prices or wages, the purchasing power of retired people is harmed considerably. To prevent this, nominal benefit payments are often increased in line with inflation. This is called *indexing benefit payments*.

In Table 1.5 we have presented, for a number of possible ways to index pension rights, the absolute and relative number of pension funds that made use of each of these ways in 2002 and 1998. In this table, only the funds are stated which had an old age pension. The category 'Other' contains for example the minimum, maximum, and average of increases in prices and wages.

Index	2002		1998	
	Number	Percentage	Number	Percentage
General price level	319	38.2	305	32.7
General wage level	38	4.6	42	4.5
Development	33	4.0	34	3.6
wages employer				
Development	37	4.4	44	4.7
wages branch of				
industry				
Periodic decision	116	13.9	129	13.8
by management				
No compensation	114	13.7	158	17.0
Other	178	21.3	220	23.6
Number of funds	835	100	932	100

Table 1.5: Numbers and percentages of bases used to index pension rights by pension funds in The Netherlands in 2002 and 1998.

Most funds provide indexation in line with the general price level. The percentage of funds that uses this base increased slightly the last five years. At the same time, the percentage of funds that do not index pension rights at all, decreased in those years.

1.1.6 Developments

In this section, we briefly describe the historical development of the size of the total asset value and the number of participants related to pension funds in The Netherlands. Then, developments up to 2002 are discussed in more detail.

Total asset value

In the last decades, the total asset value of all pension funds together has increased enormously. In Table 1.6 we present figures of the total asset values, split-up in type of pension fund for 2002 and 1998. These figures are all in billion euros. Note that the percentages of each type of fund in the total asset value remained constant in those years.

Type of fund	2002		1998	
	Amount	Percentage	Amount	Percentage
Related to a single company	143.2	29.8	88.9	29.9
The same branch of industry	320.4	66.8	198.9	66.8
Individuals	15.5	3.2	9.1	3.1
Other	0.8	0.2	0.7	0.2
Total asset value	479.9	100	297.6	100

Table 1.6: Total asset value in billion euros for every type of pension funds in The Netherlands in 2002 and 1998.

To get an even better understanding of the increase in asset values over time: the total asset value of all funds together in 1950 was approximately €1.4 billion. This number is derived from H.A. Klein Haneveld [51].

Number of participants

In Table 1.7, the total number of participants of Dutch pension funds is presented. These participants are also split-up in active members, deferred members, and retired persons.

Group	2002		1998	
	Number	Percentage	Number	Percentage
Active members	5,413,217	39.1	4,693,249	38.5
Deferred members	6,438,196	46.5	5,662,113	46.5
Retired persons	2,005,217	14.5	1,819,371	14.9
Total	13,856,630	100	12,174,733	100

Table 1.7: Total number of participants in pension funds in The Netherlands in 2002 and 1998, split-up in different groups.

We see that the total number of participants increased with more than 1.5 million people from 1998 to 2002. However, it is possible that individuals have built-up pension rights in more than one pension fund.

Recent developments (up to 2002)

At the beginning of this chapter, we have already described the recent problems many pension funds in The Netherlands have to deal with. The current situation of pension funds in The Netherlands can be summarized as follows. First of all, the interest rates are very low, see for example the website of De Nederlandsche Bank [26]. These low rates lead to a high value of the liabilities, since these interest rates are used to discount expected future cash flows.

Also expectations with respect to asset returns decreased. Moreover, Dutch pension funds have to conform to new standards with respect to recoveries in case of underfunding and to create buffers to avoid unfavorable future circumstances. The supervisor also sets bounds on parameter settings which are used in ALM studies. These new requirements by the Dutch supervisor of pension funds can be found in the circular of September 30, 2002 [74]. Finally, new international accounting standards result in more pressure on the company related to the pension fund.

Even though these circumstances look far from ideal, the financial position of pension funds can be improved in various ways:

- **Increase contributions**

An increase of contributions by active participants means that cash inflows are higher for funds. This results in a strengthened financial position. Many funds have increased the contribution rate in 2002 and 2003, for example the two largest funds in The Netherlands, ABP and PGGM, see their websites [1] and [76].

- **Remedial contribution**

The sponsor of the funds can also pay a lump-sum to the fund. A number of companies in The Netherlands have used (or consider to use) this instrument to support their pension fund. Examples of companies that (consider to) use this instrument are ABN Amro, Ahold, Akzo Nobel, Heineken, KPN, and TPG, see the website of Vereniging van Gepensioneerden Elsevier-Ondernemingen [93].

- **Incomplete indexing**

Instead of higher cash-inflows, one can also choose to give incomplete compensation (or no compensation at all) for increases in prices or wages to retired people. Of course, these retired people oppose such proposals vehemently. For that reason, retired people claim more influence in the decision making process within pension funds, see for example NRC Handelsblad [97]. According to Trouw [99], the pension fund related to the metallurgical industry breaks in 2003 with the habit of fully indexing pension rights.

- **Economize on the pension regulation**

This approach results also in a lower value of the liabilities. A possibility is to switch from a system based on final wages to a system based on average wages. In Table 1.5 we have seen such a shift. According to Trouw [100], even the regulator of Dutch pension funds considers this to be a serious option to improve the financial position of the funds.

As we have seen, the boards of pension funds have various instruments at their disposal to bring the funding ratio up to the required standard. Without doubt, a number of these instruments will meet resistance of some interested parties. This will be explained in more detail in Section 1.2.

1.1.7 International perspective

Large discrepancies exist in the field of pensions between different countries. We will discuss a few aspects for some large countries. Successively, we describe the amount of capital of pension funds, how the second pillar is financed, and the fraction of working population covered by the second pillar. Aspects with respect to supervision and regulation will be discussed in Section 1.2.3.

Capital of pension funds

In Section 1.1.6 we have seen that in 1998, pension funds in The Netherlands managed approximately €300 billion. This is more than 113 percent of the Dutch gross domestic product (GDP) in that year. The ratio of assets managed by pension funds over GDP is a measure of how much is saved for old age provisions.

In some other countries, this fraction is much lower. In Table 1.8 these ratios are presented for some large countries. These figures are from 1997 and are derived from Laboul [58]. The main reason why these numbers differ so much from country to country is the way pensions are regulated. In some countries one saves in order to build up rights. In other countries the current working population has to finance the pension payments of the old aged.

Country	Fraction assets/GDP
France	0.07
Germany	0.15
Italy	0.02
The Netherlands	1.13
Spain	0.04
United Kingdom	0.79

Table 1.8: Fraction of assets in pension funds over GDP in some European countries in 1997.

We conclude from Table 1.8 that in many countries one has hardly saved for old age provisions. This may have serious consequences in the (near) future, not only with respect to the payment of benefit payments, but also for the interest rate in the capital market. This rate may increase when countries have to borrow money in order to be able to make benefit payments. This also has macroeconomic consequences.

Pension systems

First of all, not all countries use the same way to finance the second pillar. For some major countries, the way of financing this pillar is presented in Table 1.9. These figures are based on Laboul [58].

Second-pillar schemes are usually funded, and thus generate own resources. These are based on the principle of accumulated reserves. In a pay-as-you-go system, no reserves are accumulated over time. This type of funding is more exposed to demographic risks than funded systems, see Blommestein [6]. In addition, pay-as-you-go schemes are more exposed to political risks. Most pension funds in the United Kingdom and the United States use a defined contribution system. This implies that the participant is exposed to all types of risk. Moreover, there is only limited solidarity in this system.

Country	System used to finance the second pillar
France	Pay-as-you-go for the compulsory part. Funded or pay-as-you-go for occupational pensions. Funded for the part of pensions above mandatory minimum.
Germany	Funded. Pay-as-you-go for public servants.
Japan	Funded.
United Kingdom	Funded.
United States	Funded.

Table 1.9: The way the second pillar is financed in some major countries.

Percentage of working population covered by second pillar

The percentage of working population covered by the second pillar differs from country to country. To get an idea of how much they differ, we have presented these numbers for some countries in Table 1.10. These numbers are derived from Davis [22].

Country	Percentage	Country	Percentage
Denmark	80	Portugal	15
Germany	42	Spain	15
Greece	5	Sweden	90
Italy	5	United Kingdom	50
Japan	37	United States	46
The Netherlands	90		

Table 1.10: Percentage of working population covered by second pillar schemes.

The numbers presented in Table 1.10 can mainly be explained by the fact for which percentage of the working population it is mandatory to be affiliated to a

pension system. For many people in Denmark, Sweden, and The Netherlands, participation is mandatory. On the other hand, especially in southern Europe, the percentage of working population covered by the second pillar is very low.

Even in the presence of pension schemes, individual entitlement may be subject to numerous conditions, and some categories of employees may be excluded. Forms of discrimination include age restrictions, salary restrictions, and restrictions based on sex. Not only restrictions on who can join the scheme exist in many countries, also discrimination between the sexes regarding retirement age, benefits, and mortality tables are often made.

1.1.8 Challenges

In the next few years, new challenges arise due to the aging populations in almost all major countries in the world. This is shown in Table 1.11, where OECD projections of the percentage of people of 65 and older to the population aged 15 to 64 are presented for 2010 and 2030 for some European countries. To get a feeling for these numbers, also the percentages in 1990 are given. The percentages presented in Table 1.11 are obtained from Laboul [58].

Country	1990	2010	2030
France	20.8	24.6	39.1
Germany	21.7	30.3	49.2
Italy	21.6	31.2	48.3
The Netherlands	19.1	24.2	45.1
Spain	19.8	25.9	41.0
United Kingdom	24.0	25.8	38.7

Table 1.11: Percentage of elderly over working population: estimates for 2010 and 2030 and actual data for 1990.

Of course, these figures do not imply that pension funds will be faced with problems. If everyone saves for his or her own old age provision, and assets are managed appropriately, pension funds may be able to fulfill all their liabilities, even if many people retire at the same time. However, if current active participants have to finance the pensions of the old aged, as is the case in some countries, serious problems may arise in the (near) future.

An important issue is whether also in the future the solidarity between generations and participants is guaranteed. Moreover, the question whether pensions remain affordable payable in the future will attract much attention.

1.2 ALM for pension funds

Asset Liability Management for pension funds is a risk management approach, which takes into account the assets, the liabilities, and also the interactions between the different policies which the board of a pension fund can apply. The board of a

pension fund should find acceptable policies that guarantee with large probability that the *solvency* of the fund is sufficient during the planning horizon and, at the same time, all promised benefit payments will be made. The solvency is the ability of the pension fund to fulfill all promised payments in the long-run. Usually, the solvency at a certain time moment is measured as the *funding ratio*. Recall that this is the ratio of assets and liabilities.

Underfunding occurs when the funding ratio is less than one. Another way of characterizing underfunding is by saying that the *surplus* is negative, where the surplus is the difference between the value of the assets and the value of the liabilities. The surplus is the part of the reserves of the pension fund that is not needed for paying benefit payments. The funding ratio changes over time, mainly because of fluctuations in the liabilities and in the assets. Therefore, a pension fund rebalances its asset portfolio and adjusts for example its contribution rate regularly, in order to control changes of the funding ratio over time. In case of distress, the sponsor of the fund may have to help out with a remedial contribution.

In the ALM decision process, conflicting interests of different parties exist. In the next section, we will look in more detail at the interests of different parties. In Section 1.2.2 we discuss the policies and instruments which are at the disposal of the board of pension funds. In Section 1.2.3, the way supervision is organized is described, in particular the situation in The Netherlands, but also in some other countries. The last two sections are devoted to risks and (recent) developments.

1.2.1 Interested parties in the policy of pension funds

At least five parties are involved in the decision making process by the board of a pension fund, or are interested in its results. First of all, the *active participants* are (or should be) interested. They are especially concerned about the level of the contribution rate. In particular older active participants are also interested in the degree of indexation: they would like to be compensated for inflation in all years. Active participants make contributions on a regular basis to the fund to build up rights concerning (some of) the different types of pensions described in Section 1.1.3. If the contribution rate increases for example, the active participants have to make a larger contribution to the pension fund, which results in a lower disposable income.

A second interested group consists of *retired persons* and surviving relatives of them. For this group, especially the indexing policy is important. Of course, they would like to receive full compensation for increases in prices or wages.

Also *deferred members* have interests, since they have vested rights. Therefore, they are for example concerned about the indexing policy of the fund. This interest will be explained in Section 1.2.3.

The *sponsor* of the fund is also involved. Not only does the sponsor pay a part of the regular contributions, also in case of financial distress the sponsor plays an important role. If the funding ratio drops below a certain threshold, the sponsor of the fund may contractually be forced to restore the funding ratio. On the other hand, in case of financial prosperity, the sponsor may also benefit. Note, however, that not all pension funds have a sponsor. Every pension fund related to a single company has a sponsor. Moreover, also the government may act as a sponsor of

the fund of civil servants. Other funds related to companies in the same branch of industry, or funds for individuals with the same occupation, may not have a sponsor. Next to concerns about the level of the contribution rate and the level of remedial contributions and restitutions, the sponsor is also interested in the costs associated with carrying out the pension administration.

The last party discussed here is the *supervisor* of the fund. Pension funds have to justify and report their activities to the supervisor. The role of the supervisor differs from country to country. The Dutch situation will be discussed further in Section 1.2.3.

Although all parties discussed here will be satisfied in case of financial prosperity, tensions between (some of) these groups are to be expected if the financial position of the fund is weak. Pensioners would like to receive an index-linked pension. However, this may result in even more pressure on the funding ratio, and in addition, on higher contributions by active participants or even a remedial contribution by the sponsor of the fund. On the other hand, this field of tension makes ALM problems challenging.

1.2.2 Policies and instruments

The board of a pension fund has many instruments to its disposal to control the funding ratio. These are discussed in this section. The board should take into account the interests of all parties involved in the decision making process, to find the 'best' policy mix. We stress here that the ALM process is considered from the perspective of the pension fund. Figure 1.3 shows the major policies and rules by which the fund can control the funding ratio.

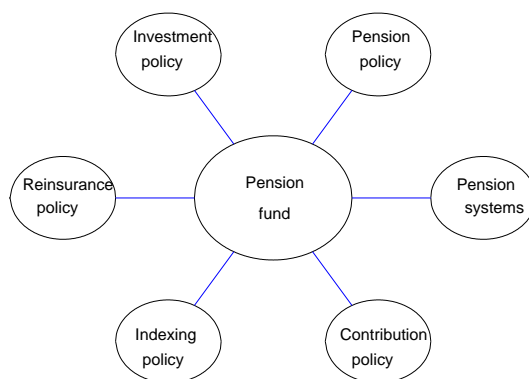


Figure 1.3: Policies and rules of a pension fund.

- **Pension policy**

The pension policy deals with decisions with respect to the different types

of pensions that the fund includes in the pension regulation. These were described in Section 1.1.3. Active participants, deferred members and retired people are interested in the pension policy, because they are the ones who will receive money from the pension fund.

- **Pension system**

The rules with respect to the benefit payments are registered in the pension rules. In these rules, the pension system is described. These were described in Section 1.1.4. Especially the sponsor and the active participants are interested in the pension rules, because they have to finance the system.

- **Indexing policy**

The indexing policy is important in valuing the liabilities and (future) benefit payments. In Section 1.1.5 we have explained what indexing is. The board of a fund has to decide which base to use, for example a consumer price index, or a wage index. Moreover, generally every year again it has to be decided whether the financial position of the fund suffices to give (full) compensation. An actuary plays a key role in this decision. Retired people, deferred members and active participants all would like to be compensated for increases in prices or wages. These are the parties who benefit from indexing pension rights.

- **Reinsurance policy**

Pension funds can sublet certain risks, like the risk of decease or disability, partially or entirely to an insurance company. This is called reinsurance and is part of the reinsurance policy of the pension fund. Reinsurance is compulsory for small pension funds in The Netherlands. The supervisor judges the reinsurance policy of pension funds. The supervisor tries to avoid that pension funds are exposed to much risk.

- **Contribution policy**

The board of a pension fund can not only manage its liabilities, also the assets can be managed. One of the instruments to manage the assets is by means of the contribution policy. In the contribution policy, the system is chosen on which the level of the contribution rate is determined. Most pension funds use a dynamic contribution rate. In this system, the level of the contribution rate can be modified in the course of time. However, it is also possible that the different interested parties involved in the decision process agree about a fixed contribution rate. The active participants and the sponsor are the parties who are mainly interested in the level of the contribution rate, because they have to finance the system. Details about the different contribution systems that exist are beyond the scope of this thesis.

- **Investment policy**

The value of the assets is also influenced by the *investment policy*. In this policy, the board of the pension fund decides in which asset classes the fund invests its assets. Also the levels of the lower and upper bounds on the fraction of the total assets invested in each asset class, and rules concerning rebalancing are part of the investment policy. For example, it is possible that

investments are made in indices, or that assets are actively managed. Also investments to reduce risks, like currency hedging, are considered. The supervisor is concerned about the investment policy, because investments directly influence the risk of underfunding. Pension funds should invest their assets such that this risk is small. To do so, rules exist with respect to levels of buffers which pension funds need if they invest in certain asset classes, see for example the circular [74].

1.2.3 Supervision

In this section, we discuss the (developments of the) tasks of the Dutch supervisor of pension funds. Moreover, the regulations for pension funds is considered. Finally, we consider some regulation issues from an international perspective.

Situation in The Netherlands (2002)

The supervisor of the Dutch pension funds is the Pensioen- & Verzekeringskamer (PVK). This authority was set up in 1923, initially to supervise the policies of insurance companies. Until 2001, this authority was named Verzekeringskamer. Only since 1952, the tasks of supervision expanded to pension funds. At the same time, the Pensioen- en Spaarfondsenwet (PSW) came into effect. The PSW is a collection of laws and a number of instructions based thereupon. In the early years, the PSW contained only a few regulations. Since the mid 1980s, the legislator interfered more and more in the contents of the pension schemes. They have done this to protect the interests of employees.

Every year, pension funds have to submit an annual report that has to be written in a prespecified way. Besides, the PVK inspects the daily affairs at the office of the funds regularly.

Because the supervision of pension funds was considered to be inadequate, the PVK got more rights on January 1, 2000. Since then, the PVK can give pension funds an instruction to bring their policies or the execution of them into conformity with legislative provisions. The PVK also has the right to impose penalties and to report to the Counsel for the Prosecution if a fund is in breach of the law. Moreover, the PVK is allowed to force pension funds to reinsure their liabilities when she considers this to be necessary for the sake of the participants.

The PSW contains rules on different fields. These are now described briefly.

- **Investment policy**

Assets should be invested in a solid way. In addition, for pension funds related to a single company, rules exist with respect to the fraction of assets which may be invested in the own company. However, no further restrictions on the composition of asset portfolios exist for Dutch pension funds. In addition, no rules concerning currency matching exist.

- **Valuation**

Liabilities are valued using a fixed discount rate. The level of this rate may not exceed 4 percent. Below we discuss recent developments in valuing liabilities.

- **Indexing**

Although the purchasing power of retired people will decrease enormously if nominal pension rights are not corrected for increases in prices or wages, the PSW does not contain any obligation to index pension rights. Therefore, indexing is based on voluntariness. However, it is possible that a fund is compelled to index benefit payments, because such a provision is part of the statutes of the fund. Generally, in the statutes is written that the board of directors of the fund every year again decides whether or not the financial position of the fund suffices to index the rights.

The only prescription with respect to the indexing of pension rights that is contained in the PSW, is a commitment of equal treatment: if retired people get a compensation, a corresponding compensation has to be given to deferred members.

Recent developments (end nineties to 2002)

To be able to judge the financial position of pension funds well, not only the assets should be valued using observed market prices, but also a market value of the liabilities should be found. This is the result of discussions between pension funds, the supervisor and consultants. However, it is far from trivial how to find a good market value for the liabilities. For a discussion of this issue, we refer to H.A. Klein Haneveld [51]. We come back to this issue in Section 5.4.

The PVK also introduces new rules pension funds have to satisfy. These rules, which concentrate on the risks with short-term and mid-term duration, are called *Financieel Toetsingskader (FTK)* and are described in [73]. The supervisor expects that these rules will come into effect from January 1, 2006. In Section 3.1 we describe these solvency tests of the supervisor in more detail.

Financial distress

In case of underfunding, the board of a pension fund immediately has to inform the PVK about this situation, see the circular [74]. Moreover, within three months the PVK should receive a recovery plan from the fund. The funding ratio should be sufficiently high again within one year.

If the funding ratio is greater than 1, but the buffers (needed for investments in risky assets) are not sufficiently large, the board also has to inform the PVK. Also in this case, the board should formulate a plan to obtain sufficiently large buffers. In this case, recovery may last two to eight years.

International perspective

In the last years, more and more attention is paid to pensions. This follows for example from the fact that two committees are established with an international character. The first is the OECD Working Party on Private Pensions, which is founded in 1999, and discusses themes like solvability, pension fund governance, and investment issues. In 2000, the International Network of Pension Regulations and

Supervisors is funded. The most important theme this committee discusses is the development of principles and best practices on the field of pensions.

In spite of these collaborations, large discrepancies exist between regulations in different countries. This will be discussed now. We concentrate again on regulations with respect to investments, valuation, and indexing.

- **Regulations concerning investments**

Requirements with respect to investments of pension funds differ much from country to country. In some countries, only guidelines are present. In other countries, rather stringent demands have to be satisfied. Although in many countries investments have to be made in compliance with rules regarding diversification and liquidity, no additional rules exist with respect to investments within one asset class.

In most countries, no restrictions are imposed with respect to currency matching. Only in very few countries, like Germany, guidelines are present.

- **Valuation methods**

The valuation of assets and liabilities generally also differs from country to country. In Table 1.12 different valuation bases are presented for different asset classes in some countries. These results are from Laboul [58].

Country	Shares (quoted)	Shares (un- quoted)	Bonds	Real estate
France	1	2	4	4
Germany	3	3	3	1
Japan	1	2	1	1
United Kingdom	5	6	5	5

Table 1.12: Valuation bases for different asset classes. The numbers have the following meaning: 1 = lower of purchase price and market value, 2 = purchase price, 3 = lowest value ever, 4 = amortized value, 5 = market value, 6 = adjusted market value.

In an international context, people try to find a consensus with respect to valuation and accounting. The International Accounting Standards Board (IABS) considers the concept *fair value* in more detail. This aim of valuing both assets and liabilities follows the International Accounting Standards no. 19 (IAS19). In IAS19, market values are used to value assets, and AAA-rated bonds are used to value liabilities.

- **Indexing**

In some countries, indexing is mandatory by law, for example in Australia and Germany. In some other countries, like Canada and Mexico, indexing is rare. In Table 1.13 the legal status in some major countries are presented. These figures are derived from Davis [22].

Country	Existence/legal status
Germany	Mandatory indexation.
Japan	Rare, except for pensions substituting to public schemes.
United Kingdom	Benefits indexation.
United States	Discretionary indexation.

Table 1.13: The existence and legal status of indexing in some major countries.

1.2.4 Risks

Pension funds are exposed to many sources of risks. As explained above, the funding ratio is very important in determining the financial soundness of a fund. As a result, one of the greatest concerns of the board of a pension fund (and also of the sponsor) is the *risk of underfunding*: the risk that the value of the liabilities is higher than the value of the assets. How the supervisor of pension funds deals with the risk of underfunding is explained in more detail in Chapter 3.

Risks are involved with the specification of every policy that is discussed in Section 1.2.2. In this section, some of these risks are mentioned. However, this list is not intended to be exhaustive. We will only stress that many sources of risk exist.

- **Risks regarding the asset portfolio**

One type of risk corresponding to making investment decisions is *currency risk*. Large pension funds usually invest their assets in internationally diversified portfolios. Currency risk is created by investments which are made in other currencies than the one in which the liabilities of a pension fund are expressed. A second source of risk with respect to the asset portfolio is the *risk of default*. Pension funds usually invest a fraction of their assets in bonds. There is always the risk that the issuer of the bond is not able to make the promised payments, which is called the risk of default. The last type of risk with respect to the asset portfolio discussed here, is the so-called *volatility risk*. This type of risk is present if the returns on the asset classes fluctuate more than expected. Risks regarding the asset portfolio are related to the investment policy of pension funds. The supervisor is concerned about this type of risk.

- **Actuarial risks**

One type of actuarial risk is the *longevity risk*. This is the risk that a participant of the fund lives longer than may be expected on the basis of mortality rates. This type of risk is concerned with old age pensions. On the other hand, also *risk of short life* is an actuarial risk. This is the risk that a participant lives shorter than expected. In this case, more benefit payments may have to be made to surviving relatives. Another type of actuarial risk arises if the liabilities are valued using a fixed discount rate, and the current interest rate in the financial markets is lower than this fixed rate. This is a risk, because the market value of the liabilities is higher in this case. The supervisor is interested in the actuarial risks pension funds are exposed to.

- **Risks with respect to contributions**

The sponsor of the fund may not be able to make its part of the contributions, or to make a remedial contribution if the financial position of the sponsor is bad. This may result in a situation in which the sponsor is contractually forced to pay, but is not able to do so. Therefore, *risk of default of the sponsor* is a source of risk from the perspective of the pension fund. Active participants may have to contribute more to the fund in this case. As a result, they are also concerned about this type of risk.

- **Risks regarding reinsurance**

Risk of default is also present if reinsurance is considered. This is the case if the insurance company is not able to make its promised payments.

- **Risks with respect to indexing**

The fund may also face risks with respect to the indexing of pension rights. For example, if the benefit payments have to be corrected for inflation by contract, high inflation rates may lead to higher than expected benefit payments, and therefore also to a higher value of the liabilities. Active participants, deferred members and retired people are concerned about the risks with respect to indexing, because they benefit from indexing pension rights.

Reducing risks

We have seen different types of risk pension funds are concerned with. However, it is also possible to reduce risks. Broadly diversified asset portfolios may reduce volatility risk for example. In addition, wise investments in derivatives reduce risks. Although pension funds are exposed to many sources of risk, they cannot go bankrupt.

1.2.5 Developments

In this section we consider some developments over the last decades in the policies, both in The Netherlands and in some other countries. First, we describe changing compositions of asset portfolios. Then, we discuss developments in valuation fundamentals.

Composition of asset portfolios

After the second world war, the composition of the asset portfolios changed dramatically. In the early years after this war, almost all assets were invested in bonds, which were not actively managed.

In the seventies, more active strategies were used to get some additional return. Also in this period, most of the assets were invested in bonds. Probably because of low returns on bonds and high inflation rates in the seventies, pension funds searched for alternative investment opportunities. Since 1983, larger fractions of the assets are invested in stocks. The changing composition of the asset portfolios are presented in Table 1.14. In this table, the category 'Other' consists of commodities,

Country	Year	Stocks	Bonds	Real estate	Cash	Other	Total
The Netherlands	1983	16	71	13	0	0	100
The Netherlands	1993	29	58	13	0	0	100
The Netherlands	2000	41	34	11	1	13	100
France	1997	12.6	43.1	7.9	6.5	29.9	100
Germany	1997	9.0	75.0	13.0	3.0	0.0	100
Italy	1997	4.8	76.4	16.7	2.0	0.0	100
Spain	1997	11.3	60.0	3.7	11.5	13.5	100
United Kingdom	1997	72.9	15.1	5.0	7.0	0.0	100

Table 1.14: Portfolio compositions of pension funds.

for instance. The data for 1983 and 1993 are derived from H.A. Klein Haneveld [52]. The data for 2000 are derived from the PVK [75].

Nowadays, most assets are actively managed. Also the geographical diversification improved: a shift has taken place in The Netherlands from mainly investing in Dutch stocks and bonds to internationally diversified portfolios. In addition, investments in derivatives, like options and futures increased. They are used to manage risks.

In many countries, the fraction of assets invested in bonds dominates the fractions invested in other asset classes. The United Kingdom is, together with The Netherlands as we have seen, an exception. Investing a large fraction of assets in a risk-free way generally leads to unnecessarily high funding costs. In Table 1.14 the composition of asset portfolios in some European countries are presented. These figures, which are derived from Laboul [58], are from 1997.

Valuation

As we have argued above, the valuation of both the assets and the liabilities is important in order to be able to give relevant information regarding the financial position of a pension fund. In addition, the valuation is important to compare the performance of one fund through time, and also to compare the position of different funds at the same time.

Nowadays, almost all assets are valued according to observed market prices. To be able to judge the financial position of pension funds appropriately, also the value of the liabilities should be based on observed market prices. However, to find a market value for the liabilities is far from trivial. For details about discussions with respect to this theme we refer to H.A. Klein Haneveld [51].

1.3 ALM models for pension funds

Asset Liability Management problems are nowadays tackled in a very different way than some decades ago. In this section we will discuss developments with respect

to tackling ALM problems. First of all, we consider the earliest ALM models. Then, we examine two techniques in more detail: simulation and stochastic programming. At the end of this section, we list the main characteristics of the ALM model presented in this thesis.

1.3.1 Earliest ALM models

The earliest Asset Liability Management models in the literature were deterministic models and duration matching techniques were applied to find the best portfolio. The stream of future benefit payments was assumed to be known in advance with certainty. Examples of these models are those of Macaulay [62], Redington [81] and Bierwag et al. [4]. These models, in which only bonds were considered as possible investments, were used until the mid 1980s. By then, bond models were used in which the future stream of benefit payments were stochastic. Examples of these models are those by Fabozzi and Fabozzi [32], Cox et al. [18], Jacob et al. [44] and Norris and Epstein [69]. Alternative portfolios were again found by duration matching techniques.

However, duration matching techniques have some major drawbacks, as is discussed by Hiller and Schaack [40]. Problems are to be expected if interest rates change unexpectedly, reinvestment risk has to be considered, and these type of models are extremely sensitive to the specific term structure model used.

1.3.2 Simulation

Only in the late 1980s, some large pension funds used the first integrated analyses for ALM problems, see Frijns and Goslings [35] and Van der Meer [64]. The first integrated analyses were made by using simulation models. H.A. Klein Haneveld and Boender were the first ones who made simulation models for ALM problems for pension funds in The Netherlands. In the literature, such a model is described by Boender et al. [7]. Because of the ability to use a lot of scenarios, simulation models for ALM problems are popular.

With simulation, the financial position of a pension fund can be calculated in many possible future circumstances. This is the big advantage of simulation techniques: a relatively large number of scenarios can be used. However, simulation techniques also have a major drawback: many choices with respect to policies have to be kept fixed. For ALM problems, this means that one has to formulate explicitly decision rules with respect to a fund's contribution policy, investment policy and indexing policy. It is very well possible that other policies than the one which is chosen, lead to better solutions, for example to lower funding costs.

1.3.3 Stochastic Linear Programming

To overcome the drawbacks of simulation, one can formulate stochastic linear programming models (SLP) to tackle ALM problems. Instead of exogenous variables (as in simulation), decisions now become endogenous. This also implies that stochastic programming is more difficult than simulation. Simulation is based on evaluation, while stochastic programming is based on optimization: SLP searches for the

best solution, given bounds on the variables, the constraints of the problem, and the objective function. SLP for ALM problems takes into account the following characteristics:

- **Uncertainty**

In ALM problems, many sources of uncertainty appear. For example, future developments of financial markets and inflation levels are all unknown yet. SLP takes these uncertainties explicitly into account (although the specification has to be given by the user of course).

- **Dynamics**

For ALM problems, dynamics (more time periods) is essential. At each specified decision moment in time, SLP takes into account both previous decisions (like the composition of the asset portfolio and the level of the contribution rate) and the possibility to adjust these decisions at a later decision moment, based on revealed values of uncertain parameters.

- **Linear constraints**

As we will see in the next two chapters, constraints for ALM problems can be written as linear constraints. Moreover, many details can be described in this way, as we will also see in Chapter 2.

These characteristics make SLP very attractive to use in solving ALM problems. For a general survey of stochastic programming we refer to Prékopa [80], Birge and Louveaux [3] and Kall and Wallace [47].

The major constraint of this solution technique is its relatively long solution time. This is the reason why in practice ALM problems are ‘solved’ by simulation. However, due to algorithmic progress and technological developments, nowadays relatively large models can be solved by SLP in reasonable time.

In the academic world, stochastic linear programming for finance problems were developed by Kallberg et al. [48], and Kusy and Ziemba [57]. SLP attracted a lot of attention by the paper of Cariño et al. [14]. They used this solution technique for an ALM problem for a large Japanese insurance company. Another ALM model for insurance companies is the one by Mulvey et. al. [67]. Also in the banking industry stochastic programming is used. Examples of ALM models for banks are those by Klaassen [49], Bradley and Crane [12], Lane and Hutchinson [59], Dempster and Ireland [23], and Mulvey and Vladimirov [68].

ALM models for pension funds appeared in Consigli and Dempster [17], Dert [24], Kouwenberg [55], and Hilli et al. [41]. We can solve ALM models with more scenarios and states than is done in Consigli and Dempster [17]. It is hard to compare the sizes of the problems Dert considered, with the ones presented in this thesis. This follows from the fact that Dert, who is the only one who uses binary decision variables in his ALM model, uses additional states (which do not have successors). This will be explained in more detail in Chapter 3. Kouwenberg solved models with more scenarios and states than we can in reasonable time. He used many processors at the same time to solve problems, while we solved the problems on a single machine. Other applications of stochastic programming in ALM for pension funds are for example those by Dupačová and Polívka [29] and Bogentoft et al. [8].

1.3.4 Main characteristics of our ALM model

The ALM model presented in this thesis is much more detailed than the ones presented in the literature. The key ingredients of our ALM model are described briefly now.

- **Contribution rate**
The contribution rate has to satisfy lower and upper bounds. Moreover, large deviations in two consecutive years are penalized.
- **Risk constraints**
The expected next year's shortage with respect to a certain level of the funding ratio may not exceed a prespecified value, which depends on the value of the liabilities.
- **Indexing**
Indexing is considered to be an instrument of the board of pension funds. Therefore, if the financial position of the fund is weak, the board may decide not to compensate (or to compensate only partially) for increases in prices or wages.
- **Underfunding and remedial contributions**
If in a prespecified number of consecutive years the fund faces underfunding, the sponsor of the fund has to restore the funding ratio to a prespecified level by means of a remedial contribution.
- **Horizon effects**
At the horizon of the model, which is the last moment at which decisions are modelled, surpluses and shortages with respect to certain levels of the funding ratio are rewarded and penalized, respectively.

This list does not contain all characteristics of the ALM model; it gives an idea of some important aspects. For a detailed overview of the ingredients of our model, we refer to Chapter 2.

One of the properties of our model is its *flexibility*, in two ways. First of all, there is a flexible way of modeling *solvency risk*:

- The level of the funding ratio is compared with different standards. Moreover, we compare these levels at different times.
- Short term risks are considered with a fixed upper bound (which is to be set by the user of the model).
- Mid-term risks are taken into account by means of a remedial action of the sponsor after a number of consecutive years (to be specified by the user) in which underfunding is registered.
- Long term risks are considered by means of penalizing underfunding with respect to a prespecified level of the funding ratio at the horizon.

Second, there is a flexible way of modeling interactions between parties involved in the decision making process. This is done by introducing soft constraints and penalties. The interaction between the parties can be represented by choosing appropriate parameter settings with respect to:

- Contribution rates (the levels of the lower and upper bounds, and penalty parameters associated with changes in the levels of the contribution rates).
- Penalties associated with underfunding with respect to a prescribed level of the funding ratio at the horizon.
- Fixed penalty costs. These are important to penalize the unfavorable events. In our model, these fixed penalty costs are used next to proportional penalty costs (to penalize the level of unfavorable events like the amount of underfunding).

In the above listing, we mentioned that some values of the parameters are to be specified by the user of this model. Of course, some of these levels may for example be prescribed by the supervisor.

1.4 Summary

In the next two chapters, we focus on the formulation of our ALM model. To be able to present this model in the context of SLP, we first introduce scenarios and the decision structure in Chapter 2. Moreover, in that chapter the largest part of our ALM model will be built. Special attention is paid to (model) indexations and flexible risk measures. These risk measures require that if the funding ratio is too low in a number of consecutive years, the sponsor is forced to make up the deficit. In Chapter 3 we describe newly proposed risk criteria introduced by the Dutch supervisor of pension funds and how these criteria are linked to the risk constraints we incorporate in our ALM model. Especially the risk of underfunding in one year will be considered.

As a result of the introduced flexible risk constraints, and introduced fixed penalty costs for unfavorable events, binary decision variables (i.e. variables which have either the value 0 or 1) are unavoidable. Therefore, we obtain a multistage mixed-integer stochastic program, which is a very difficult optimization problem in general (see e.g. Römisch and Schultz [82]). It is therefore not to be expected that optimal solutions can be found in reasonable time for realistically sized instances. This is the reason why we consider a heuristic approach in finding solutions. This heuristic, which is described in Chapter 4, iteratively searches for improvements such that all constraints are satisfied. In this heuristic, insights into the problem are used. The numerical results show that heuristic solutions can be found for these large-scale mixed-integer stochastic programs.

In the formulation of the multistage SLP, scenario trees are used to model the uncertain future. In Chapter 5 we describe how numerical values for the returns on the asset classes and the changes in the general wage level are found. Also future changes in the (market value of the) liabilities and discount rates are considered.

In Chapter 6 the results of some numerical experiments are described. In that chapter, we consider an illustrative case in detail. We also describe some impressions obtained by considering some alternative modeling choices, and other scenario trees.

As we will see, the ALM model described in this thesis closely fits the developments and interests in society. Indeed, we incorporate the laws as prescribed by the Dutch supervisor of pension funds in our model. Moreover, relative positions of the interested parties can be represented by choosing appropriate parameter values. However, it is not easy to find a suitable setting for the parameter values. Moreover, more research is needed to analyze the source of the (extreme) sensitivity with respect to the set of scenarios used. These (and other) conclusions will be described in Chapter 7.